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Mapping past and recent landscape modifications in the Lagoon of Venice through geophysical surveys and historical maps

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ABSTRACT

The Lagoon of Venice (Italy), the biggest lagoon in the Mediterranean, surrounds the historical city of Venice. Its fate is closely intertwined with that of the city, which is itself endangered today by sea level rise. Major modifications are ongoing to protect the city from flooding with the building of mobile barriers at the lagoon inlets. Other plans exist for future dredging of a large navigation channel close to the city center. In this context, a large geophysical survey explored the lagoon sub-bottom. In this study we reconstructed past and recent landscapes extending from the period before the creation of the lagoon up to present day. Crossing our data with environmental records provided by the city's historical archives, allowed several phases of the lagoon's evolution to be distinguished. Using radiocarbon dating and acoustical sub-bottom reconstruction, we mapped a dense network of palaeochannels corresponding to different hydrologic conditions. One of these palaeochannels related to the alluvial channel that crossed the Venice subsoil. Overall, the results of this study show that the number of channels decreased substantially over the centuries. Explanations for this reduction include natural causes, such as the increase of the mean sea level and natural subsidence, as well as human activities, such as artificial diversion of rivers and modifications of the inlets. Comparison with historical maps showed that this tendency for fewer channels increased dramatically in the last century.

Introduction

Lagoons are widely distributed throughout the world ocean coasts. They constitute about 13 percent of the total world coastline (Barnes, 1980). They represent 5.3 percent of European coastlines (Razinkovas et al., 2008), with more than 600 lagoons in the Mediterranean area alone (Gaertner-Mazouni and De Wit, 2012). From geological and geomorphological viewpoints, coastal lagoons are ephemeral systems that can change in time (becoming estuaries or infilled; Davies, 1980). The nature of this change depends on the main factors controlling their evolution, such as mean sea level, hydrodynamic setting, river sediment supply and pre-existing topography. As observed by Duck and da Silva (2012), however, these coastal forms are seldom if ever allowed to evolve naturally. They are often modified by human intervention typically to improve navigability or in attempts to maintain the environmental status quo. By controlling their depth and topography, humans have exploited them for many centuries for food production (fisheries, gathering of plants and algae, salt extraction, aquaculture, etc.) (Chapman, 2012). These modifications can transform radically the lagoon ecosystem.

Human activities have also influenced the evolution of the Lagoon of Venice (Italy) over the centuries (Gatto and Carbognin, 1981; Favero, 1985; Carbognin, 1992; Ravera, 2000; Brambati et al., 2003; Tosi et al., 2009). Together with the historical city of Venice, the Venice Lagoon is a UNESCO World Cultural and Natural Heritage Site. The first human remains in the lagoon area date back to the upper Paleolithic age (50,000–10,000 BC). The lithic remains found in Altino (Fig. 1a) show that the first settlements date back to almost 7000 years ago (Marsale, 1986; Bianchin Citton, 1994; Fozzati, 2013). Strong archeological evidence suggests that the islands within the northern Lagoon have been inhabited since Roman times and up to the Medieval Age. Examples of wooden waterside structures were found dating back between the first century BC and the second century AD (Canal, 1998, 2013; Fozzati, 2013). As explained in Housley et al. (2004), due to the need for dry land suitable for building, salt marshes were enclosed and infilled to support small islands on which early settlements were built. Sites that go back to Roman imperial times are now well documented in the northern part of the lagoon. In the city of Venice itself, however, the first archeological evidence found so far dates back to the 5th century AD. Only later, in the 8th to 9th

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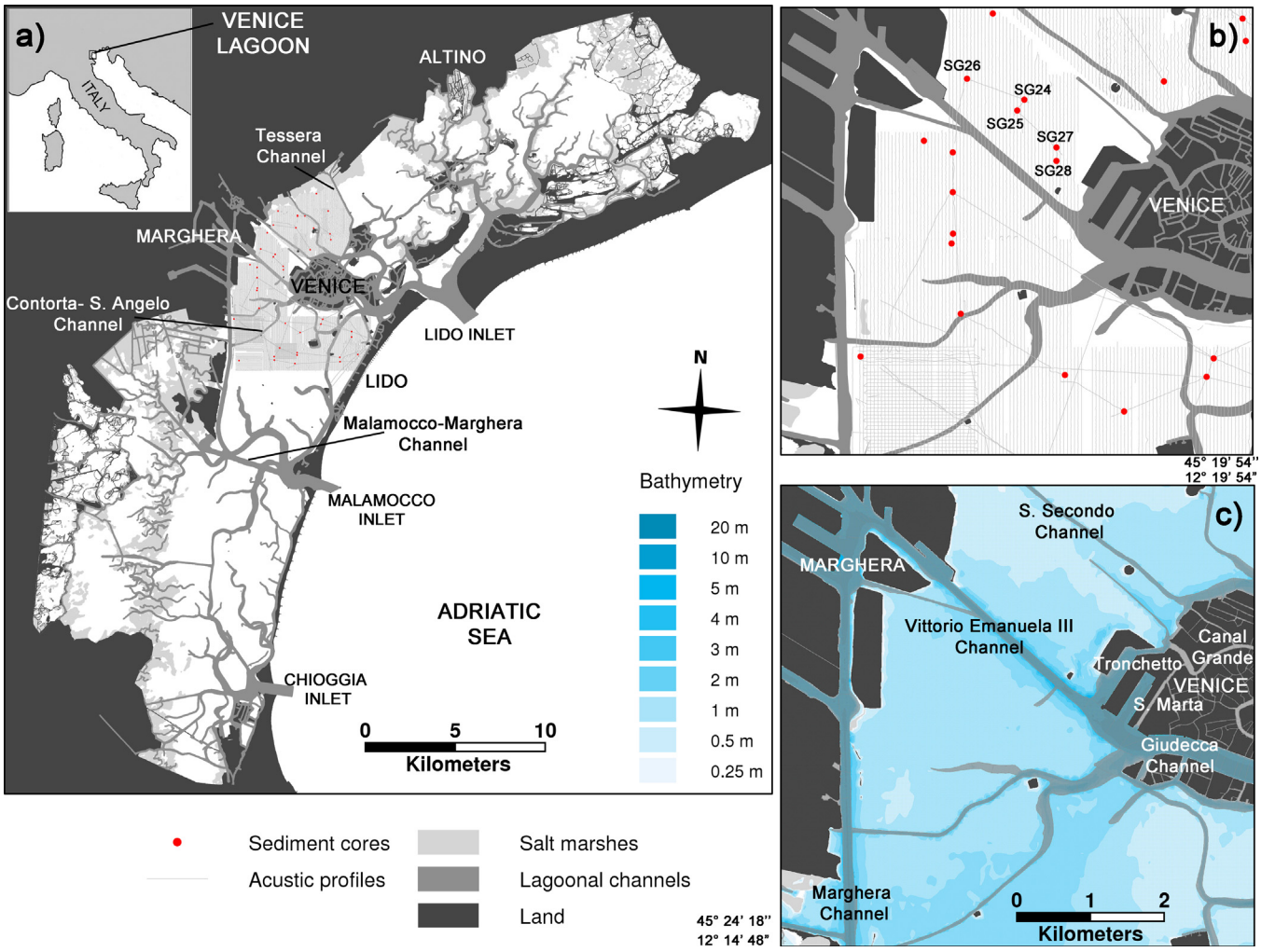

Fig. 1. (a) Map of the Venice Lagoon with the survey area of about 45 km^2 surrounding Venice to the north-east and south; (b) a zoom of the study area. The dense set of parallel survey lines with 50 m spacing is plotted together with the position of the cores (red points); (c) bathymetry of the study area.

century AD, did Venice start to take the character of a city (Ammerman, 2003). By the end of the 13th century, Venice was a prosperous city with a population of about 100,000 inhabitants (Housley et al., 2004).

At the beginning of the 12th century, sediment delivered by the system of rivers threatened to fill the lagoon (Gatto and Carbognin, 1981). In the short term, the infilling of sediment affected the navigation and harbor activity of Venice, while in the long term, it opened up the city to military attack by land. This situation motivated the Venetians to divert the rivers away from the lagoon, so that the sediment load of the rivers would discharge directly into the Adriatic Sea. This human intervention was carried out over the next few centuries so that all the main rivers flowing into the lagoon were diverted by the 19th century (Favero, 1985; Bondesan and Furlanetto, 2012). If the Venetians had not intervened, the fate of the Venice Lagoon could have been the same as that of a lagoon in the central part of the Gulf of Lions in the south of France. This lagoon was completely filled between the 12th and 13th century (Sabatier et al., 2010).

In the 19th century, significant modifications included a reduction of the number of inlets from eight to three. The depth of the remaining inlets also increased from ~5 m to ~15 m, with a consequent increase in tidal flow and erosive processes (Gatto and Carbognin, 1981). In the last century, dredging of major navigation channels took place in the central part of the lagoon to enhance the harbor activity. The exploitation of underground water for the industrial area of Marghera (Fig. 1) contributed to a sinking of the bottom of the basin (Carbognin, 1992; Brambati et al., 2003). Also, the lagoon surface decreased by more than 30 percent due to activities associated with land reclamation and fish-breeding. The morphological and ecological properties of the lagoon changed dramatically: salt marsh areas decreased by more than 50 percent (from 68 km^2 in 1927 to 32 km^2 in 2002) and some parts of the lagoon deepened (Carniello et al., 2009; Molinaroli et al., 2009; Sarretta et al., 2010). Moreover, flooding caused by sea level rise (Carbognin et al., 2010) is currently threatening the historical city of Venice, so much so that major construction of mobile barriers at the lagoon inlets is ongoing (MOSE project, Magistrato alle Acque, 1997). These changes at the inlets affect substantially the lagoon environment (Tambroni and Seminara, 2006; Ghezzo et al., 2010).

This study focuses on the central part of the bottom of the lagoon directly surrounding the city of Venice in order to answer the following questions: First, what was the landscape of the central lagoon before the first human settlements? Second, what were the consequences of the major river diversions? Third, what were the consequences of dredging new navigation channels during the last century?

Historically, the shallowness of the lagoon (average depth about 0.8 m) has prevented the use of acoustic/seismic methods that are generally implemented for the reconstruction of ancient landscapes.